REMARKS

Claims 1-12 and 17-26 are pending. Withdrawn Claims 13-16 are canceled.

I. Information Disclosure Statement of July 31, 2002

Applicant thanks the Examiner for returning the Form PTO-1449 filed on July 31, 2002 with an IDS with the current Office action. However, the last reference on the Form PTO-1449 was neither initialed nor crossed off by the Examiner. Thus, Applicants request the Examiner return another copy of the Form PTO-1449 indicating the reference has been considered. In the event the reference was misplaced, Applicants attach a copy to this response (ATTACHMENT I, B. Stok and A. Mihelic, "Optimal design of the die shape using nonlinear finite element analysis", in Simulation of Materials Processing: Theory, Methods & Applications (1995) pages 625-630).

II. 35 USC § 102

Claims 1-8, 12, 17-18, 20-21 are rejected under 35 USC 102(b) as being anticipated by Sun (US 6,044,676). The Office action asserts Sun discloses every element of independent process claim 1 and apparatus claim 17 and the above-mentioned dependent claims. Applicants respectfully contend this is not the case.

A. Process Claim 1

Sun relates to a method of making aluminum beverage containers which reduces the likelihood of galling occurring by controlling the tooling geometry used in can-making (see e.g., col. 3, lines 26-35). Galling occurs when aluminium from a preceding can adheres to the die. There is no mention of using the method for metal sheet coated on at least one side with a plastic coating layer. In contrast, Claim 1 recites "moving product with a plastic coating layer."

Present Claim 1 recites moving the product along the forming surface of the wall-ironing tool, and the forming surface comprises a starting zone and a subsequent zone where the entry angle is smaller in the starting zone of the forming surface than in the subsequent zone. Thus, the product contacts these zones.

Paragraph 4 of the Office action asserts Sun, Fig. 2 shows a starting zone where die and workpiece first meet followed by a subsequent zone labeled 123 in the figure which has an entry angle larger than that of the starting zone. It is respectfully submitted this assertion is not correct.

The chamfer 139 does not contact the metal workpiece but serves to direct coolant fluid into the space between the ironing die and the can wall (Sun, col. 5, lines 1-4, and col. 5, lines 31-55). Thus, it is not a starting zone where die and workpiece first meet.

Column 5, line 8- column 6, line 7 and column 6, lines 48-55 of Sun explain that the ironing die 120 illustrated in Figure 2 has chamfer 130 which has a radius 131 between the chamfer 130 and the working surface 123 (referred to as 128 in the description). The radius 131 between the chamfer 130 and the working surface 123 of the die also serves to provide better coolant diversion to the working zones of the ironing die (col. 6, lines 48-65, working surface 123 erroneously denoted as 138). The area referred to by the Office action as being the starting zone does not form part of the forming surface of the die as it does not even contact the workpiece but instead has as its object to direct lubricant/coolant.

Page 2, lines 6-9 of the present application explains in the starting zone with the small entry angle a high pressure is built up in the plastic-coated material on all sides. Page 1 lines 29-37, explains this increases the fracture limit of many plastic materials during forming. The pressure built up is maintained in the subsequent forming in the subsequent zone with a larger entry angle than that of the starting zone. As the fracture limit of the plastic is increased a larger entry angle in the subsequent zone can be selected without undue risk of the plastic layer breaking and being stripped off the metal sheet (page 1, lines 26-28). Larger entry angles are beneficial as they result in a longer service life for a wall ironing tool (page 1, lines 24-26).

Sun does not mention or hint towards wall-ironing metal coated with a plastic layer nor is there any suggestion or motivation to modify the wall-ironing die disclosed in Sun to result in a process comprising contacting its workpiece with a starting zone and a subsequent zone of a forming surface, wherein the starting zone has a smaller entry angle

than the subsequent zone and thereby solve the problem of a plastic coating being stripped off a metal sheet during wall-ironing.

The present invention as set out in claim 1 is thus novel and inventive over Sun.

B. Apparatus Claim 17

As explained above, the chamfer zone 123 of Sun Fig. 2 is designed to not contact the metal workpiece (Sun, col. 5, lines 1-4). Thus, Sun does not disclose a forming surface having a starting zone and a subsequent zone, the entry angle being smaller in the starting zone than in the subsequent zone.

III. Rejections under 35 USC § 103

A. Claims 9-11, 19 and 22-25

Claims 9-11, 19 and 22-25 are rejected as being unpatentable over Sun.

It is respectfully submitted that, as explained in the present application, these features further distinguish over Sun.

B. Claims 1-12 and 17-25

The Office action has also objected to claims 1-12 and 17-25 as being unpatentable over Jansen (US 4,881,394). As the Office action acknowledges, Jansen does not disclose the configuration of a forming surface comprising a starting zone and a subsequent zone wherein the entry angle is smaller in the starting zone than in the subsequent zone.

Jansen discloses a method and apparatus for wall ironing a deep-drawn cylindrical body which gives a high thickness reduction in a small number of reduction stages (col. 1, line 67- col. 2, line 3). The method uses two ironing ring die regions with a relatively small thickness reduction occurring in the first phase and relatively large thickness reduction occurring in the second phase and requires hydrodynamic lubrication to occur in the second die region. Figure 2 shows the double reduction ring according to the invention of Jansen. The entry angle α_1 to the first die region 6 is disclosed in column 3, lines 61-68 as being in the range 8-10° but preferably 8°. The entry angle to the second die region 7 is disclosed in column 4 lines 14 as being in the range 5-10° more preferably

5-7° and most preferably about 6°. Thus, Jansen teaches the entry angle of the first region should preferably be greater than the entry angle of the second region.

The Office action argues the present invention is obvious as Jansen discloses a range of configurations and it has been held that discovering the optimum workable range involves only routine skill in the art. The Office action quotes *In re Aller*, "[W]here the general conditions of a claim are disclosed in the prior art it is not inventive to discover the optimum or workable ranges by routine experimentation".

However, it is respectfully submitted Jansen does not disclose all the general conditions of Claim 1 as it does not disclose that the metal sheet to be processed is coated on at least one side with a layer of plastic. Thus, Jansen lacks the motivation to achieve the present invention. Jansen has already determined and disclosed the optimum values of entry angle for the first and second die regions to obtain the objects it set out to achieve, namely of achieving hydrodynamic lubrication of the second die region (col. 2, lines 34-50).

Jansen does not mention wall-ironing metal sheet coated on at least one side with a layer of plastic nor does it mention the problems of the plastic layer breaking and being stripped off the metal sheet when a larger entry angle is selected. Thus, it does not suggest the present process (Claim 1) or apparatus (Claim 17) designed to work with plastic coated metal sheet.

The observation in the present application, page 1, lines 29-30, that many plastic materials exhibit a higher fracture limit during forming as the pressure on all sides increases is also not mentioned in Jansen. The solution offered by the present invention to the problem of being able to use a larger entry angle without the plastic layer breaking and being stripped off the metal sheet cannot be obtained by routine experimentation based on the disclosure of Jansen.

It is only with impermissible hindsight that the solution offered by the present invention to the problem of being able to use a larger entry angle without the plastic layer breaking and being stripped off the metal can be obtained from Jansen.

The present invention thus involves inventive skill and is not obvious in view of the disclosure of Jansen.

C. Dependent Claims

At least Claims 2, 5, 6, 11, 12, 18, 19, 21, 22 and 25 further distinguish over the reference.

D. Claim 26

Claim 26 is rejected as being unpatentable over Sun in view of WO94/22607 or Jansen in view of WO 94/22607. It is respectfully submitted WO '607 does not make up for the deficiencies of Sun or Jansen.

IV. Conclusion

In view of the above, it is respectfully submitted that all objections and rejections are overcome. Thus, a Notice of Allowance is respectfully requested.

Respectfully submitted,

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ATTACHMENT I

B. Stok and A. Mihelic, “Optimal design of the die shape using nonlinear finite element analysis”, in Simulation of Materials Processing: Theory, Methods & Applications (1995) pages 625-630.

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Optimal design of the die shape using nonlinear finite element analysis

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ABSTRACT: A finite element based approach to optimal process design in steady-state metal forming is considered. In particular, the optimization is applied to the problem of a wire drawing die design. Conical and streamline dies are investigated, their shape being parametrized by a polynomial function. Optimal design is effected by enforcing minimization of the forming energy consumption. The same algorithm is used also for determination of possible area reduction. In both investigated problems several technological and geometry constraints are taken into account. From the comparison between the numerical results and known solutions for rigid plastic material model, it is demonstrated that the solutions are trustful, and can be applied efficiently for more realistic material model not only in reducing the total energy consumption, but also in preventing the formation of defects and the die wear.

1. INTRODUCTION

The main preoccupation of any manufacturing research regarding a real industrial production is how to improve its actual quality and efficiency, both in technical and economical sense. Determination of the related process and design parameters, fulfilling these aspirations, is in principle equivalent to a solution of the correspondent optimization problem. Depending on the product requirements or customer's needs the optimization criteria concerning the same problem may differ, but whatever the process design criteria may be, it is only our thorough understanding of the physics governing the problem that can ensure an efficient optimal solution. When referring to metal forming processes it would not be possible to reliably design the material flow, or to predict and prevent the occurrence of eventual defects, without a sufficient knowledge of the influence that process variables, such as friction, material physical properties, and workpiece geometry, have on the process evolution.

In the past it was the empirical experience which predominantly governed the process design. But nowadays, with computer-aided techniques well established also in the metal forming industry, a designer should rely the refinement of his design much more on information obtained by the computer process simulations. These simulations, which are based mainly on the finite element computational models, are an efficient means for the identification of the process response under boundary conditions, imposed by the investigated tool geometry and process kinematics. Although these models have room for further improvement they are of great importance for a design engineer by enabling him a quantitative estimation of the spatial distribution and time evolution of the process variables.

Optimization in structural engineering is rather frequent in practice, mostly because of its relative simplicity due to the linear material behaviour. It is rather obvious that an optimal solution related to metal forming is directly related to the material flow. Unfortunately, a mathematical description of this process is far away of being simple. In fact the process is characterized by an extreme complexity due to nonlinearities arising from the inelastic behaviour of the formed material, large deformation and contact boundary conditions at the material-tool interface. Further, when the amount of heat, generated because of irreversibility of the plastic deformation and interfacial friction, is not negligible the material physical parameters exhibit an additional temperature dependence. Neverthe-

less, when considering an efficient integration of classical mathematical methods of optimization and the finite element concept, and attained reliability of the computational analysis of metal forming processes, it seems that despite all complexity application of optimization to the area of metal forming and to problems associated with the correspondent tool design is possible.

In this paper the optimization of extrusion processes is considered. Actually, the material flow in the cold wire drawing process is optimized by proper design of the die's geometry. Starting from an initial die design, an optimized design solution, based on nonlinear optimization procedures [1], is found. Two optimization objectives have been imposed separately, first, minimization of the energy consumption, and second, maximization of the possible wire reduction.

2. FORMULATION OF THE OPTIMAL DESIGN PROBLEM

Experience proves that geometry of a die used in cold extrusion and drawing processes is of extreme importance, its influence on the overall process performance being essential. Usually, conical dies are used, while their contour is chosen by experience, taking process parameters, such as area reduction, forming rate, material flow stress curve and interfacial friction conditions, somehow into account. Since it is evident that an optimized die design solution depends directly on the given process parameters, an optimal design problem could be set regarding this choice. Also, considering the fact that modern tool manufacturing enables production of relatively inexpensive dies of more complex shapes, it is not reasonable to limit our investigation to conical dies only.

In what follows we address two different optimization problems associated with optimal die design in wire drawing process. Regarding the imposed optimization objectives they can been stated as follows:

PROBLEM I:

MINIMIZE:	*total energy consumption*
Subject to:	*stress constraints*
	die geometry constraints

PROBLEM II:

MAXIMIZE:	*area reduction*
Subject to:	*stress constraints*
	die geometry constraints

Introducing s for the process state variables and d for the design variables, and $\Psi_0 = \Psi_0(s,d)$ for the objective function and $\Psi_i = \Psi_i(s,d)$ for the constraint functions, respectively, a mathematical formulation of the stated optimal problems can be written as

FIND d TO EXTREMIZE:

$$\Psi_0 = \Psi_0(s,d) \tag{1}$$

Subject to:

$$\Psi_i(s,d) \leq 0 \,, \quad i = 1,\dots,\alpha \tag{2}$$

$$\Psi_i(s,d) < 0 \,, \quad i = \alpha - 1,\dots,\beta \tag{3}$$

The stress constraints (2) are associated with possible technological defects arising due to an inadequate stress field distribution and flow pattern. The die geometry constraints (3), however, impose the geometric consistency in the forming zone. Although the above equations define the framework within which an optimal solution is to be sought, this system is not sufficient. Actually, it has to be enlarged by taking governing equations of the process considered and the correspondent boundary conditions into account. Without entering into a detailed description of the thermomechanics of metal forming processes this set of equations can be written in the following form

$$R(s,d) = 0 \tag{4}$$

It is evident that this relation establishes an implicit dependence of the process state variables s on the design variables d

$$s = s(d) \tag{5}$$

The fulfilment of equation (4) in view of the optimal design problem (1-3), yields a solution of the considered problem. This solution can be solved, for instance, by a sequential quadratic programming (SQP) method which is considered to be one of the most reliable optimization methods [1]. In accordance with the method a quadratic subproblem is formulated and solved to get a search direction, which is followed afterwards by a line search to obtain an improved design solution.

3. DESIGN SENSITIVITY ANALYSIS

For an efficient optimal solution search strategy a sensitivity of the system response variables, i.e. state variables s, to changes in design variables d is required. Consequently, a sensitivity analysis of the objective and constraint functions is to be performed. When possible it is performed analyti-cally by direct differentiating the response func-tions $\Psi(s,d)$. Analytical treatment is advantageous since it ensures highest accuracy and relatively low computational time. But in general, when the respective functions are complex numerical ap-proaches have to be used.

The simplest numerical procedure is the one associated with the finite difference concept. Accordingly, the partial derivative $\frac{\partial \Psi}{\partial d}$ is approxi-mated by

$$\frac{\Delta \Psi}{\Delta d} = \frac{\Psi(s^0, d^0 + \Delta d) - \Psi(s^0, d^0)}{\Delta d} \tag{6}$$

where a perturbation from the current problem solution (s^0, d^0) is given by a step size vector Δd, the components of which are linearly independent.

4. NUMERICAL IMPLEMENTATION IN VIEW OF APPLICATION TO WIRE DRAWING

The analysis of the problem specified by equa-tion (4) has to be treated numerically. It has been successfully proved several times also in our experience that the finite element method is reliable and appropriate to tackle high computa-tional complexity encountered in process analyses [8,9,10].

With Lagrangian incremental elastic-plastic formulation assumed to model the material flow, the general purpose finite element program ABAQUS [11] has been employed to simulate the cold wire drawing process in the present study. The optimization has been performed upon the finite element analysis results and finite difference sensitivity analysis by the NLPQL computer code developed by K. Schittkowski [2].

A pre-processor that allows a finite element discretization of the problem domain and its automatic adaptive remeshing in accordance with the intermediate optimized design solutions has been designed.

Since wire drawing is mainly a steady-state process, some attention is needed when modelling this state numerically. In fact, plastic deformation of a control volume in a drawn wire is dependent on the stress history, which is in the considered case imposed implicitly by a time variation of the volume initial and boundary conditions. In order to identify properly the steady-state response, a careful tracing of the process time evolution is required from the very beginning. Drawing of a wire through a die is imposed in the numerical model (Fig. 1) by applying the displacement of the wire's front section incrementally.

For purposes of this investigation a die has been assumed rigid while friction at the die-workpiece interface has been modelled by assuming the Coulomb friction law with an upper bound τ_{max} on the frictional shear stress.

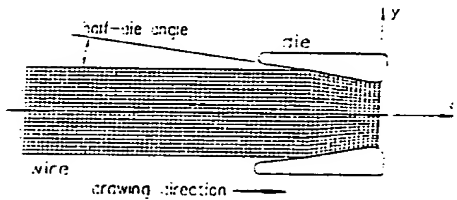

Figure 1: Finite element model of the wire drawing process

In order to perform an optimal die design a mathematical description of the die's contour is needed. In our case we have chosen a polynomial form

$$\begin{aligned} Y(x, a_0, a_1, \ldots, a_n) = {} & \frac{d_1}{2} + (x - x_1)\,tg\,a_0 + \\ & + (x - x_1)(x - x_0)(a_1 + a_2 x + a_3 x^2 + \\ & + \ldots + a_n x^{n}) \end{aligned} \tag{7}$$

where $Y(X)$ stays for the die radius at axial position x and d_1 for the final diameter of the drawn wire, while x_0 and x_1 are the inlet and outlet die coor-dinates in the axial direction. They can be readily determined from the area reduction data.

Evidently, the polynomial assumption (7) ensures smoothness of the die shape by function definition, while from the optimization point of view this selection results in relatively small number of design variables, which are in fact the polynomial coefficients a_k. Since description (7)

includes also a linear variation of the die radius $Y(x)$ it can be used for analysing both, conical and streamline dies.

Finally, let us consider mathematical structures of the objective and constraint functions associated with the two specified optimal design problems.

In the Problem I the objective is to find such die angle of the conical die or such polynomial function for the streamline die, that the required forming energy be minimized. The drawing force being closely connected to the forming energy the optimization problem remains equivalent when referred to the drawing force minimization. Considering the numerical model the total drawing force is represented by the resultant of the nodal forces at the wire's front section

$$\Psi_0 = \sum_{i=1}^{N} F_i(a_k) \tag{8}$$

At this stage of investigations we have decided to consider only one stress constraint, actually the one associated with the prevention of the wire necking and subsequent collapse. The correspondent mathematical form takes the resultant of the Mises equivalent stresses in a cross section of the extruded wire as competent measure. Again, by considering the finite element discretization the discussed constraint can be written in the following form

$$\Psi_1 = \frac{\sum_j \sigma^j_{eqv}}{\sum_j C\sigma^j_{yield}} - 1 \le 0 \tag{9}$$

where summation is taken columnwise over the nodes of a reference cross section. The above constraint states that the actual stress state, measured by the sum of the equivalent stresses σ^j_{eqv}, should be less or equal to the sum of the correspondent yield stress state, measured by the sum of the current yield strength σ^j_{yield}, multiplied by a safety factor C.

Considering the die geometry constraints two inequalities bounding the die radius $Y(x)$ with respect to the feasible design can be set

$$\Psi_2 = \frac{2\cdot Y(x,a_k)}{D_0} - 1 \le 0 \tag{10}$$

In the Problem II the maximal area reduction is sought by considering fixed die design. In this

$$\Psi_3 = 1 - \frac{2\cdot Y(x,a_k)}{D_1} \le 0 \tag{11}$$

case the design variable is the initial wire diameter D_0.

For this case the objective function is formulated as

$$\Psi_0 = \left[1 - \left(\frac{D_1}{D_0}\right)^2\right]\cdot 100 \tag{12}$$

While the stress constraint is identical to the one in the Problem I, the geometry constraints reduce to only one of the following form

$$\Psi_2 = \frac{D_1}{D_0} - 1 \le 0 \tag{13}$$

5. NUMERICAL EXAMPLES

For the present investigation the wire has been modelled by 75 x 10 four-node axisymmetric elements. Also, only for reasons of comparison with the published results [4,5], the wire material is assumed to behave elastic-ideally plastically, with the yield strength being σ_{yield}=650N/mm². For the same reason coefficient C=0.975 in the constraint equation (9) has been assumed.

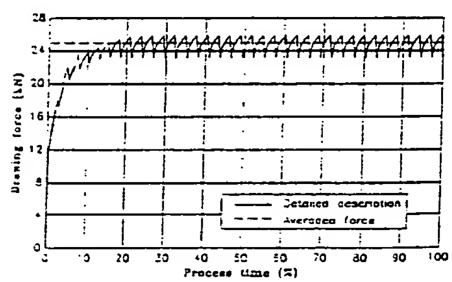

Figure 2: Typical oscillations observed by the FEM analysis

First, let us discuss some general findings. Using the default ABAQUS increment adjustment did not yield satisfactory results, since the wire often detached from the die at the die-land part. This happened even for the admissible selection of the area reduction and die half-angle. After some trials the increment size capable of reliable modelling was found to be approximately 20% of the average

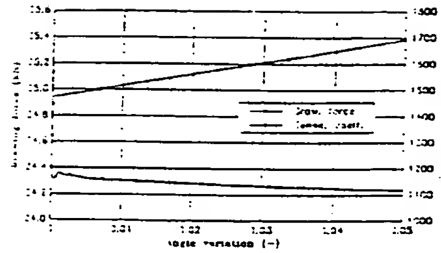

Figure 3: Function value and sensitivity results for small angle variation

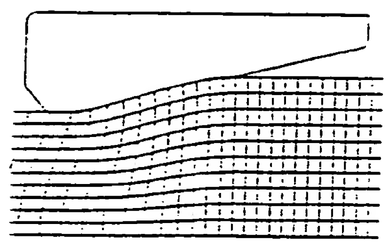

Figure 5: The optimal shape of the stream line die

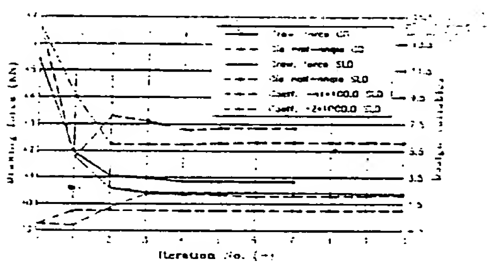

Figure 4: Iteration history and comparison for conical and streamline dies

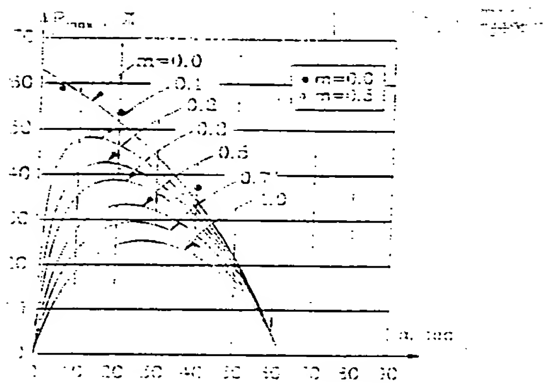

Figure 6: Comparison of the numerical and known Avitzur's solutions

finite element length.

The plotted curve in Fig. 2 exhibits "time/increment" dependence of the drawing force which is evidently a consequence of the discretization effect when modelling contact boundary conditions. The remedy to reduce these oscillations is the mesh and incrementation refinement.

With respect to the above discussed oscillating of the analysis results, the objective function has to be appropriately averaged in order to perform sensitivity and optimization at all. By doing this the only possibility to calculate the sensitivity analysis is by the finite difference approach. However, wherever possible derivatives are computed analytically.

To check the accuracy of the design sensitivity predicted by the finite difference scheme a series of analyses has been performed. The function value and sensitivity for the drawing force are shown in Fig.3. According to these investigations the step size vector is selected to be 0.1% of the design variable.

As an illustrative example for the Problem I, i.e. the minimization of the drawing force, the computer program based on the discussed theory is applied to the optimization of conical and streamline dies. The streamline die profile is described by three design variables.

In both cases the die half-angle is initialized to the value $\alpha = 15.0°$. The extruded diameter is 15mm, while the area reduction is 20%. The friction conditions on the die-wire interface are specified by friction coefficient $\mu = 0.05$ and shear factor $m = 0.2$. The results of the performed optimization are plotted for both, the conical and streamline die in Fig. 4. The performed optimization yields, considering the constraint functions as defined in section 4, optimal die half-angles of values $\alpha = 7.20°$ and $\alpha = 6.09°$ for the conical die and streamline die, respectively.

When comparing the optimized drawing forces which are actually 40.8kN for the conical die, and 40.4kN for the streamline die, it is rather surprising that the difference is so small, in fact only about 1%. However, when observing the graphical blow-up in Fig.5, these results become quite reasonable.

As an illustrative example for the Problem II, i.e. the maximization of the possible reduction, the

computer code is applied only to the optimization of the conical die. The optimization was performed for several reductions and for two different friction conditions, namely, for $m=0$ and $m=0.5$. The results of the performed optimization are plotted in Fig. 6, and they agree quite good with known solutions [4,5], especially for the $m=0$.

6. CONCLUDING REMARKS

It is demonstrated in the present paper that the optimization techniques can be very efficient in controlling process parameters by allowing for an appropriate choice of die design. Consequently, significant cost savings and product improvements can be achieved. Hence, methods used in the structural shape optimization have been shown as useful tool also when applied to the design of wire-drawing dies.

The iterative optimization scheme requires evaluation of the design sensitivities, therefore an efficient method for calculating the design sensitivities is generally quite important. However, by a proper die shape representation the total number of the gradient analyses can be reduced. It has been demonstrated that by assuming a polynomial function with three design variables satisfactory results can be achieved.

It seems that the most time consuming part of needed computations is the actual finite element analysis. Namely, to consider the problem as a quasi-steady one, the analysis has to go on until the response quantities in a control volume become steady. Only then, the values needed for the optimization can be considered.

In the near future a series of the parametric studies should be made and compared to the existing solutions.

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